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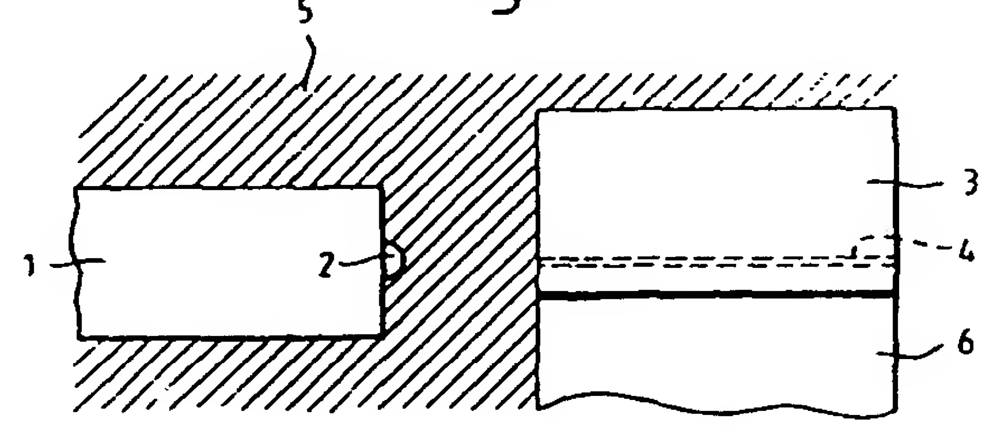
(54) Optical coupling equipment for an optical semiconductor and an optical fiber.

(57) Optical coupling equipment of the invention for an optical semiconductor and an optical fiber comprises an optical semiconductor (3,4,6), an optical fiber optically coupled to the semiconductor, and a refraction index matching substance (5) filling the space between the semiconductor and the fiber (1). The refraction index matching substance has a refraction index greater than 1 and smaller than the refraction index of the core of the fiber. The optical distance between the ends of the semiconductor and the fiber with the ends of convex tip (2) changes in association with the refraction index of the refraction index matching substance. If the differences in refraction index between the core of the fiber, as measured on the convex tip, and the outside ... creases, the position of the focus of the conv... changes. Furthermore, if the substances exist... side the active layer, the radiation angle of the ... diode also decreases. As a result, the distanc... tween the facing ends which provides the high... coupling efficiency increases, compared to the equipment lacking the substance.

Fig. 2



EP 0 589 711 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 30 7578

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	EP-A-0 054 300 (MISUBISHI DENKI KABUSHIKI KAISHA) * page 3, line 14 - line 30; figure 2 *	1,3,15	G02B6/42
X	EP-A-0 466 975 (MITSUBISHI DENKI KABUSHIKI KAISHA) * column 3, line 31 - line 41 * * column 3, line 54 - column 4, line 16; claims 1,3-5; figure 3 *	1,13,14	
X	PATENT ABSTRACTS OF JAPAN vol. 10, no. 264 (P-495) 1986 & JP-A-61 090 108 (NEC CORP) * abstract *	1,2	
A	EP-A-0 116 481 (SOCIÉTÉ ANONYME DE TÉLÉCOMMUNICATIONS) * page 10, line 32 - line 34 *	5-7	
A	PATENT ABSTRACTS OF JAPAN vol. 17, no. 20 (P-1469) 1993 & JP-A-04 245 204 (DAINIPPON INK & CHEM INC) 1 September 1992 * abstract *	8	TECHNICAL FIELDS SEARCHED (Int.Cl.5) G02B
D,A	APPLIED OPTICS., vol.19, no.15, 1980, NEW YORK US pages 2578 - 2583 KUWAHARA ET AL. * abstract *	12	
A	IBM TECHNICAL DISCLOSURE BULLETIN., vol.26, no.4, September 1983, NEW YORK US pages 2177 - 2178 CHAMBLISS ET AL. * the whole document *	4,13,14	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	27 February 1995	Hylla, W

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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(54) Optical coupling equipment for an optical semiconductor and an optical fiber.

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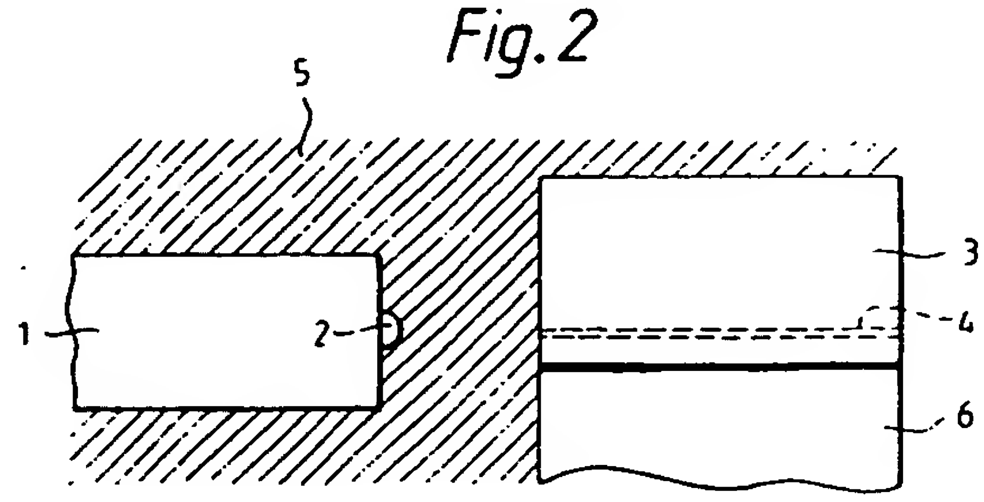
Fig. 2



EP 0 589 711 A2

perfluoro compound such as perfluorocarbon or perfluorotrialkylamin. In both of the conventional equipment and embodiment, the fiber 1 is constituted by a single mode fiber having a field radius of 10 μm and an outside diameter of 125 μm. At the hemispherical end 2, the core of the fiber 1 protrudes about 5 μm and has a radius of curvature of 5 μm.

The coupling characteristic of the equipment of the present invention and that of the conventional equipment as determined by simulation are as follows. In accordance with the present invention, the refraction index matching substance 5 filling the space between the end of the active layer 4 of the laser diode 3 and the convex tip 2 of the fiber 1 changes the optical distance between them and, therefore, the coupling characteristic between the diode 3 and the fiber 1.

Fig. 3 compares the equipment of the present invention and the conventional equipment with respect to a relation between the distance between the laser diode and the fiber in the direction parallel to the optical axis and the coupling loss, as determined by simulation. For the simulation, the equipment of the present invention included a refraction index matching substance whose refraction index was 1.275, while the conventional equipment did not include it. It is to be noted that the half width value of the laser diode 3 is 25 degrees in both of the directions perpendicular to and parallel to the active layer, and that the radiation light is approximated by Gauss distribution. As shown in Fig. 3, in the conventional equipment, when the distance between the laser diode 3 and the fiber 1 is 10 μm, the coupling loss is about 0.2 dB; the coupling efficiency is highest. On the other hand, when the refraction index matching substance 5 exists between the laser diode 3 and the fiber 1, the optical distance between the ends of the diode 3 and fiber 1 changes in associated with the refraction index of the substance 5. In addition, since the difference in refraction index between the core of the fiber 1, as measured on the convex tip 2, and the outside decreases, the position of the focus of the convex tip 2 changes. Furthermore, if the substance 5 exists outside the active layer 4, the radiation angle of the laser diode 3 also decreases. As a result, the distance between the facing ends which provides the highest coupling efficiency increases, compared to the equipment lacking the substance 5. Specifically, when the refraction index is 1.275, the distance which minimizes the coupling loss is about 30 μm.

Regarding the coupling loss which provides the highest coupling efficiency, it is about 0.2 dB in the conventional equipment and about 2 dB in the equipment of the present invention, meaning a fall by about 2 dB. However, the refraction index matching substance 5 reduces the change in the coupling loss in the direction parallel to the optical axis, compared to the equipment lacking it. With the illustrative embodiment, a permissible displacement about 2.5 times greater than that of the conventional equipment is achievable. It follows that the equipment of the present invention allows a minimum of change in coupling loss to occur even when the position is deviated in the direction parallel to the optical axis, although lowering the coupling efficiency at the optimum position.

Fig. 4 is a graph comparing the equipment of the present invention and the conventional equipment with respect to a relation between the displacement in the direction perpendicular to the optical axis of the laser diode and fiber and the coupling efficiency, as determined by simulation. The radiation angle of the laser diode 3 is 30 degrees. As the graph indicates, when the refraction index matching substance 5 is absent, the permissible displacement from the position where the coupling is optimum to the position where the coupling loss falls 2 dB is less than 1 μm. By contrast, when the substance 5 is present, the permissible displacement is about 2 μm which is about twice the conventional one.

With the conventional equipment, it is difficult to couple the laser diode 3 and fiber 1 without positional adjustment. The equipment of the present invention noticeably broadens the permissible displacement range in both the direction parallel to the optical axis and the direction perpendicular thereto. Moreover, such a permissible displacement range allows the laser diode 3 and fiber 1 to be coupled without resorting to fine adjustment. Hence, the equipment can be assembled simply by mechanically positioning and fixing the laser diode 3 and fiber 1, enhancing productivity to a significant degree. In addition, once the equipment is assembled, the coupling loss changes little even if the relative position of the laser diode 3 and fiber 1 is changed due to a change in ambient temperature or similar factor.

Further, the refraction index matching substance 5 filling the gap between the laser diode 3 and fiber 1 reduces the difference in refraction index between the core of the fiber 1 and the outside, as mentioned earlier. This reduces Fresnel reflection light at the end of the core 1 and, therefore, the reflection light to the active layer 4 of the laser diode 3, thereby insuring the stable operation of the laser diode 3.

In accordance with the present invention, even when the ambient temperature changes, the output light can be maintained substantially constant without resorting to an APC circuit. Fig. 5 shows a relation between the distance between the laser diode 3 and the fiber 1 and the coupling loss

particular to the equipment of the present invention and determined by simulation by changing the refraction index of the refraction index matching substance. As shown, in the equipment using the refraction index matching substance, the coupling characteristic changes in association with the refraction index. Specifically, when a refraction index matching substance having a small refraction index is used, the distance between the laser diode and the fiber which provides the optimum coupling efficiency, as well as the coupling loss, is small. The above-mentioned distance and coupling loss increase with an increase in refraction index. Generally, as the temperature rises, the threshold current of a semiconductor laser diode and a differential quantum efficiency decrease. It follows that coupling loss at high temperature can be reduced if the laser, diode is located at a position which will set up optimum coupling at high temperature beforehand, and if use is made of a refraction index matching substance whose refraction index decreases with an increase in temperature. As a result, when the light output power of the laser diode changes due to a change in ambient temperature, the coupling loss is changed to correct the output light.

When a semiconductor laser diode is coupled to a single mode fiber, the output light of the fiber changes with a change in ambient temperature, as shown in Fig. 6. The graph of Fig. 6 was derived from simulation. For the simulation, the refraction index of the refraction index matching substance was caused to change at a rate of $-3.5 \times 10^{-4}/{}^\circ C$, while the output light was caused to decrease at a rate of -0.036 mW/$^\circ$C relative to the increase in the temperature of the laser diode. As the graph indicates, when the refraction index matching substance is absent, the output light changes about 2 dB in response to a temperature change in the range of from $-40^\circ C$ to $+80^\circ C$. By contrast, when such a substance is used, the output light does not change more than 1 dB. In this manner, the present invention is capable of maintaining the output light of the fiber substantially constant without controlling the injection current by an APC circuit.

The result of evaluation of a semiconductor laser diode module implemented with the coupling equipment of the present invention will be described. Figs. 7 and 8 respectively show semiconductor laser diode modules using conventional coupling equipment and the coupling equipment of the present invention.

The optical fiber 1 is a single mode fiber having a core diameter of 10 µm and an outside diameter of 125 µm. The end of the fiber 1 is cut in a mirror configuration. Further, the tip of the fiber 1 is chemically etched by hydrofluoric acid and then melted by heat to form the hemispherical lens-like convex end 2. The fiber 1 is affixed by a resin in a V-shaped groove formed in the surface of a mount 7 by chemical etching. On the other hand, the semiconductor laser diode 3 is constituted by an InGaAsP semiconductor and provided with a wavelength of 1.3 µm and a radiation angle of about 29 degrees. The laser diode 3 is soldered to the mount 7. A particular mark is provided on the surface of the mount 7 for positioning the laser diode 3 on the mount 7. The laser diode 3 and fiber 1 are mechanically positioned such that the optical axis of the active layer 4 of the laser diode 3 and that of the core of the fiber 1 align with each other. The mount 7 carrying the laser diode 3 and fiber 1 is accommodated in a package 8.

The equipment of the present invention filled with the refraction index matching substance and the conventional equipment lacking such a substance were evaluated with respect to coupling characteristic. The result of evaluation is as follows.

To begin with, in the equipment of the present invention, the package 8 is filled with the refraction index matching substance 5 implemented by perfluorotrialkylamin which has a refraction index of 1.29 at room temperature. A lid 9 hermetically seals the package. Fig. 11 plots the temperature dependency of the refraction index of perfluorotrialkylamin. As shown, the refraction indiex changes at a rate of $\Delta n = -3.5 \times 10^{-4}/{}^\circ C$ and sequentially decreases with the increase in temperature. In the temperature range of from $-20^\circ C$ to $+80^\circ C$, the refraction index substantially linearly changes from 1.304 to 1.269.

Fig. 9 compares the equipment of the present invention and the conventional equipment with respect to a relation between the displacement of the laser diode in the direction parallel to the optical axis and the coupling loss. Fig. 10 compares them with respect to a relation between the displacement in the direction perpendicular to the optical axis and the coupling loss.

As shown in Fig. 9, when the laser diode and fiber assume a position which minimizes the coupling loss, the coupling loss of the conventional equipment is about 2 dB. By contrast, the coupling loss of the present invention is about 4.5 dB which is about 2.5 dB greater than is conventional. However, the rate of increase in coupling loss relative to the displacement of the laser diode in the direction parallel to the optical axis is greater in the conventional equipment than in the equipment of the present invention. For example, assuming a fall of coupling loss by 2 dB, a permissible displacement of about 30 µm is achievable with the laser diode of the present invention, while it is only about 5 µm in the conventional equipment.

As shown in Fig. 10, the permissible displacement available with the equipment of the present invention is greater than that of the conventional equipment even in the direction perpendicular to the optical axis. Specifically, assuming an increase in coupling loss by 2.5 dB, the equipment of the present invention achieves a permissible displacement of about ±2.5 dB, while the conventional equipment has a permissible displacement of only about ±1 μm. Presumably, why the coupling characteristic deviated from the result of simulation is, mainly, that the convex tip of the fiber used for experiment was not completely hemispherical.

The equipment of the present invention and the conventional equipment will be compared with respect to the stability of coupling characteristic against the varying ambient temperature. Fig. 12 shows a relation between the injection current and the light output power (I-L characteristic) of a semiconductor laser diode as determined without using the refraction index matching substance. When implemented with the laser diode having such an I-L characteristic, the equipment of the present invention and the conventional equipment each changes the light output from the associated optical fiber in a particular manner, as shown in Fig. 13. The injection current to the laser diode was fixed at 30 mA while the ambient temperature was changed from room temperature up to 85°C. In this condition, the output light drops only about 0.5 dB in the equipment of the present invention, but it drops about 2 dB in the conventional equipment. When the ambient temperature is changed in the range of from -40°C to +85°C, the output light changes about 0.7 dB in the equipment of the present invention, but it changes more than about 2 dB in the conventional equipment. Therefore, with the equipment of the present invention, it is possible to maintain the output light of the fiber substantially constant against the varying ambient temperature, without resorting to the control over injection current. This stems from the fact that the refraction index matching substance filling the coupling section corrects the coupling efficiency, and the fact that the substance enhances heat radiation from the laser diode and/or otherwise assists in the removal of heat from the diode, eg. by conduction, whereby to reduce the change in output light with the varying temperature. The equipment of the present invention makes it needless to control the injection current by an APC circuit since it maintains the variation of output light ascribable to ambient temperature less than 1 dB.

Fig 14 which was generated by computer simulation shows the relation between the refractive index and optical coupling efficiency. The results assume that the radius of the hemispherical lens-like convex end 2 of an optical fibre is 5μm, and that the radiation angle of a laser diode is 27 degrees. As shown in Fig 14, when the refractive index n = 1.3, the optical coupling efficiency is comparatively low (about 3 dB loss) and the tolerance of the coupling efficiency to variations in the coupling distance between a laser diode and an optical fibre is high.

Using a refractive coupling medium having n = 1.2 produces only 1dB loss at a coupling distance of 20 μm and the tolerance to coupling distance variation is still better than if air (n = 1) is the coupling medium. Further, if a loss of (say) 6 or 7 dB can be accepted, the use of a coupling medium with n = about 1.4 (for example a silicon oil) permits very wide variations in coupling distance to accommodated. Thus is will be appreciated that, within the generality that the refractive index n of the index-matching coupling medium should be greater than 1 and less than the index of the optical fibre (n for a typical fibre being about 1.45), various values or ranges of n may be preferred. For example, ranges having approximate lower limits of 1.15, 1.2 and 1.25, and approximate upper limits of 1.35, 1.4 and 1.45 are contemplated. Any of the lower limits may be combined with any of the upper limits.

While the end of the optical fiber has been shown and described as being a convex tip, the present invention is practicable even with an optical fiber having a flat end.

Instead of a laser diode, the optical semiconductor element may be a light emitting diode. Further, when the optical semiconductor element is an avalanche photodiode or similar photodetector, the refraction index matching substance reduces the difference in refraction index between the core of the fiber and the outside as well as the difference in refraction index between the light-sensitive surfaces of the photodetector and the outside. Then, the Fresnel reflector light is reduced on the end of the fiber and the light-sensitive surface of the photodetector. As a result, the reflection light from the fibre end and from the light-sensitive surface to the transmission path is reduced, thereby reducing the extent to which transmission quality is lowered by multireflection. In addition, since the reflection loss on the end of the fiber and the light-sensitive surface is reduced, sensitivity to light is enhanced.

In summary, it will be seen that the present invention provides optical coupling equipment which eases permissible displacement accuracy requirement and, therefore, increases productivity while insuring stable optical coupling. Also. the equipment reduces the optical loss due to Fresnel reflection light on the end of an optical semiconductor element and the end of an optical fiber, thereby promoting the stable operation of a semi-

conductor laser diode. Moreover, the equipment can minimize the change in the output light of the fiber, which is coupled to the laser diode, without resorting to an APC circuit.

It is to be noted that the coupling equipment of the present invention can couple not only a light emitting element and an optical fiber but also a photodetector and an optical fiber. When applied to a photodetector and an optical fiber, the equipment reduces, among others, Fresnel reflector light from the end of the fiber and the light-sensitive surface of the photodetector, thereby preventing transmission quality from being degraded by multireflection.

Various modifications will become possible for those skilled in the art after receiving the teachings of the present disclosure (which are by way of example only) without departing from the scope of the invention as defined by the following claims.

Claims

1. Optical coupling equipment comprising an optical semiconductor (3), and an optical fiber (1) optically coupled thereto via a refraction index matching substance (5) filling a space between said optical semiconductor and of said optical fiber (1).

2. Equipment as claimed in Claim 1, wherein said refraction index matching substance (5) has a refraction index greater than 1 and smaller than a refraction index of a core of said optical fiber.

3. Equipment as claimed in Claim 1 wherein said refraction index matching substance has a refraction index of less than 1.45.

4. Equipment as claimed in any preceding claim, wherein said refraction index matching substance (5) has a refraction index which decreases with an increase in temperature.

5. Equipment as claimed in any preceding Claim, wherein said refraction index matching substance (5) comprises a liquid.

6. Equipment as claimed in Claim 5 wherein said liquid comprises a silicone oil.

7. Equipment as claimed in any of Claims 1 to 4, wherein said refraction index matching substance (5) comprises a gel.

8. Equipment as claimed in any of Claims 1 to 4 wherein said refraction index matching substance (5) comprises a fluoric resin.

9. Equipment as claimed in any of Claims 1 to 4, wherein said refraction index matching substance (5) comprises perfluorotrialkylamine.

10. Equipment as claimed in Claim 9, wherein said perfluorotrialkylamine comprises a fluoric resin including a composition represented by a formula $(C_5F_{11})_3N$.

11. Equipment as claimed in Claim 9, wherein said perfluorotrialkylamine comprises a fluoric resin including a composition represented by a formula $(C_4F_9)_3N$.

12. Equipment as claimed in any preceding claim, wherein said optical fiber (1) has an end of hemispherical convex configuration through which it is optically coupled.

13. Equipment as claimed in any preceding claim, wherein said optical semiconductor (3) comprises a light emitting element.

14. Equipment as claimed in Claim 13, wherein said optical semiconductor (3) comprises a semiconductor laser diode.

15. Equipment as claimed in any of Claims 1 to 12, wherein said optical semiconductor (3) comprises a photodetector.

Fig.1 (Prior Art)

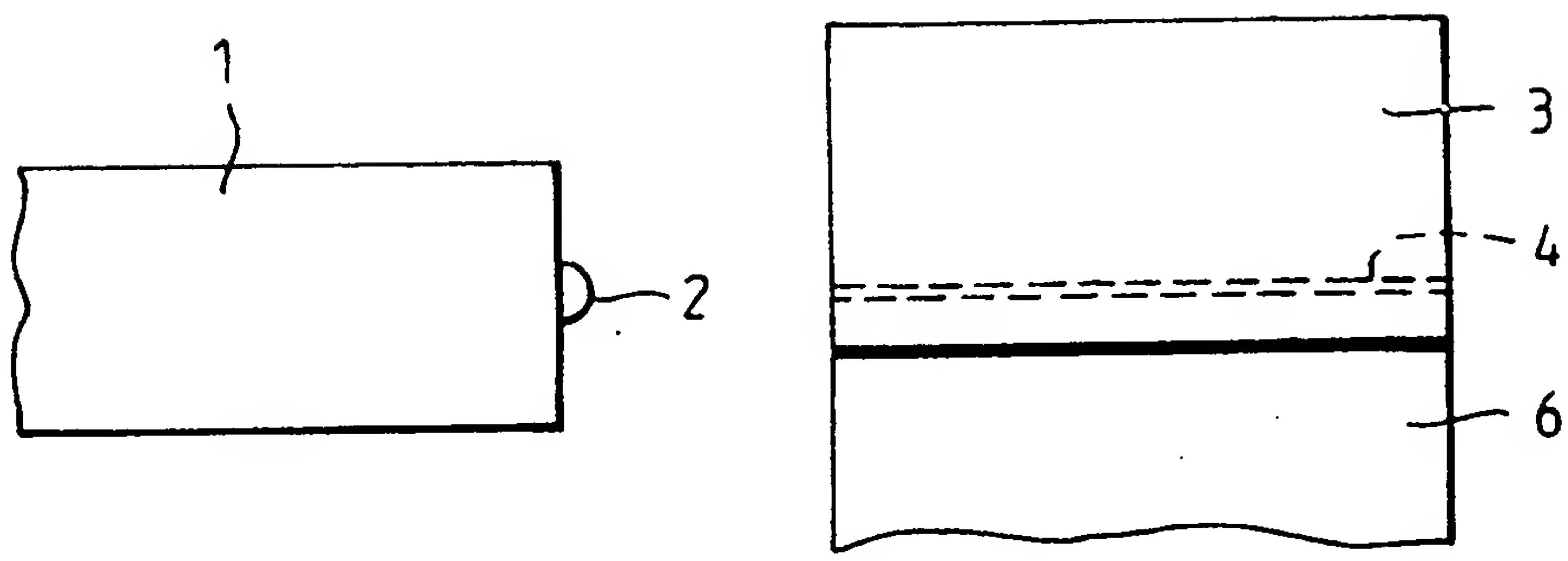


Fig. 2

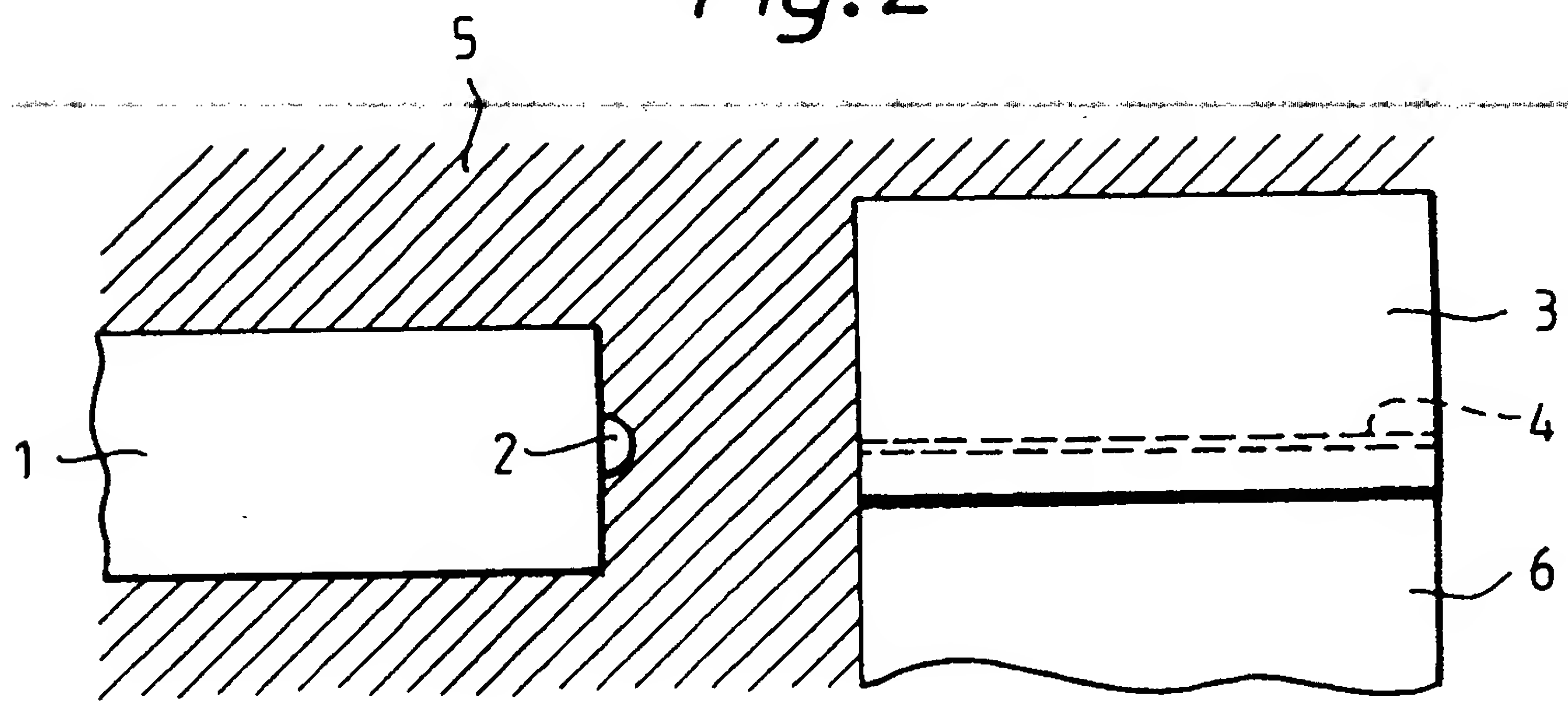


Fig.3

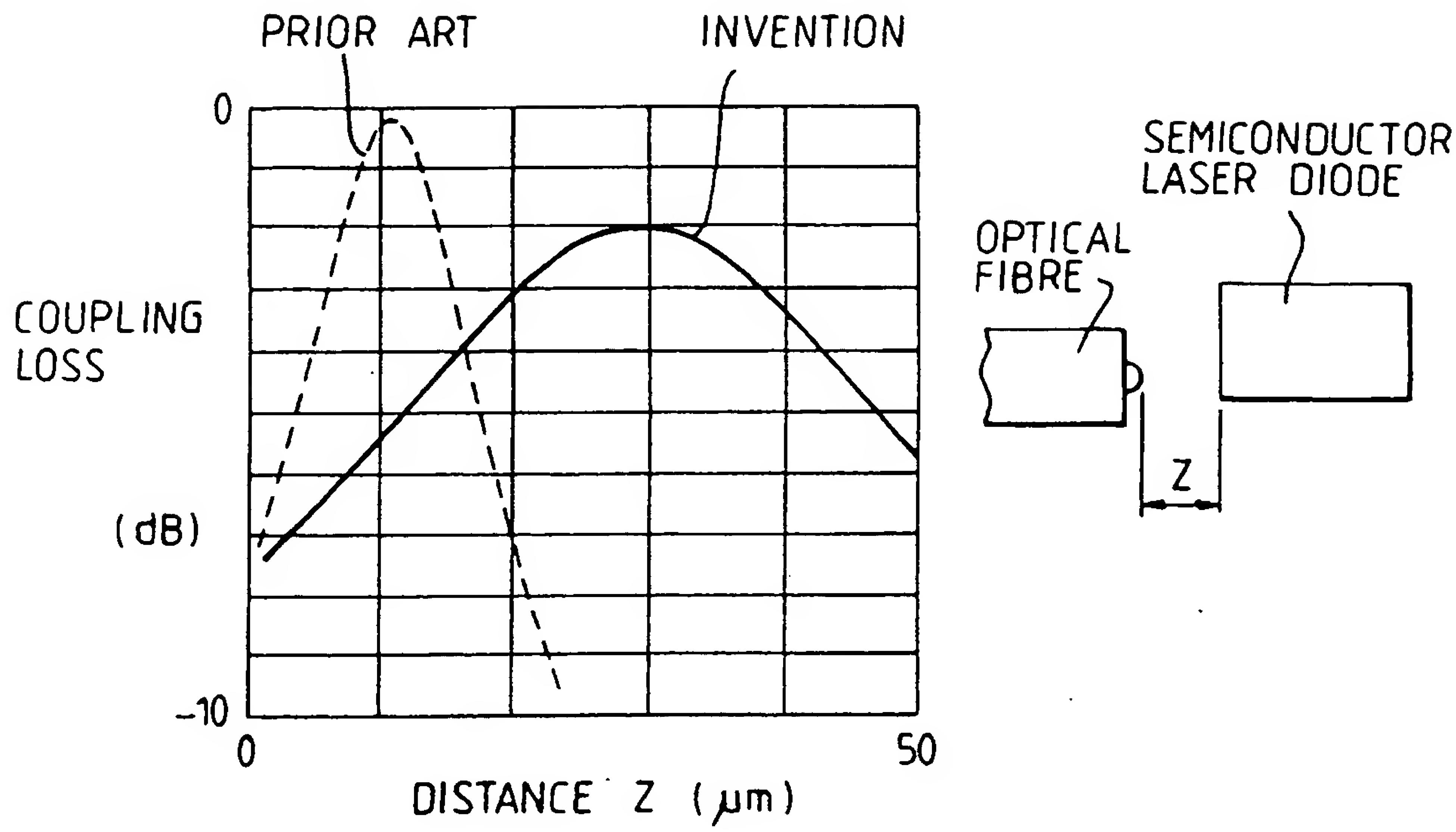

PRIOR ART
INVENTION
0
-10
COUPLING LOSS
(dB)
0
50
DISTANCE Z (μm)
SEMICONDUCTOR LASER DIODE
OPTICAL FIBRE
Z

Fig.4

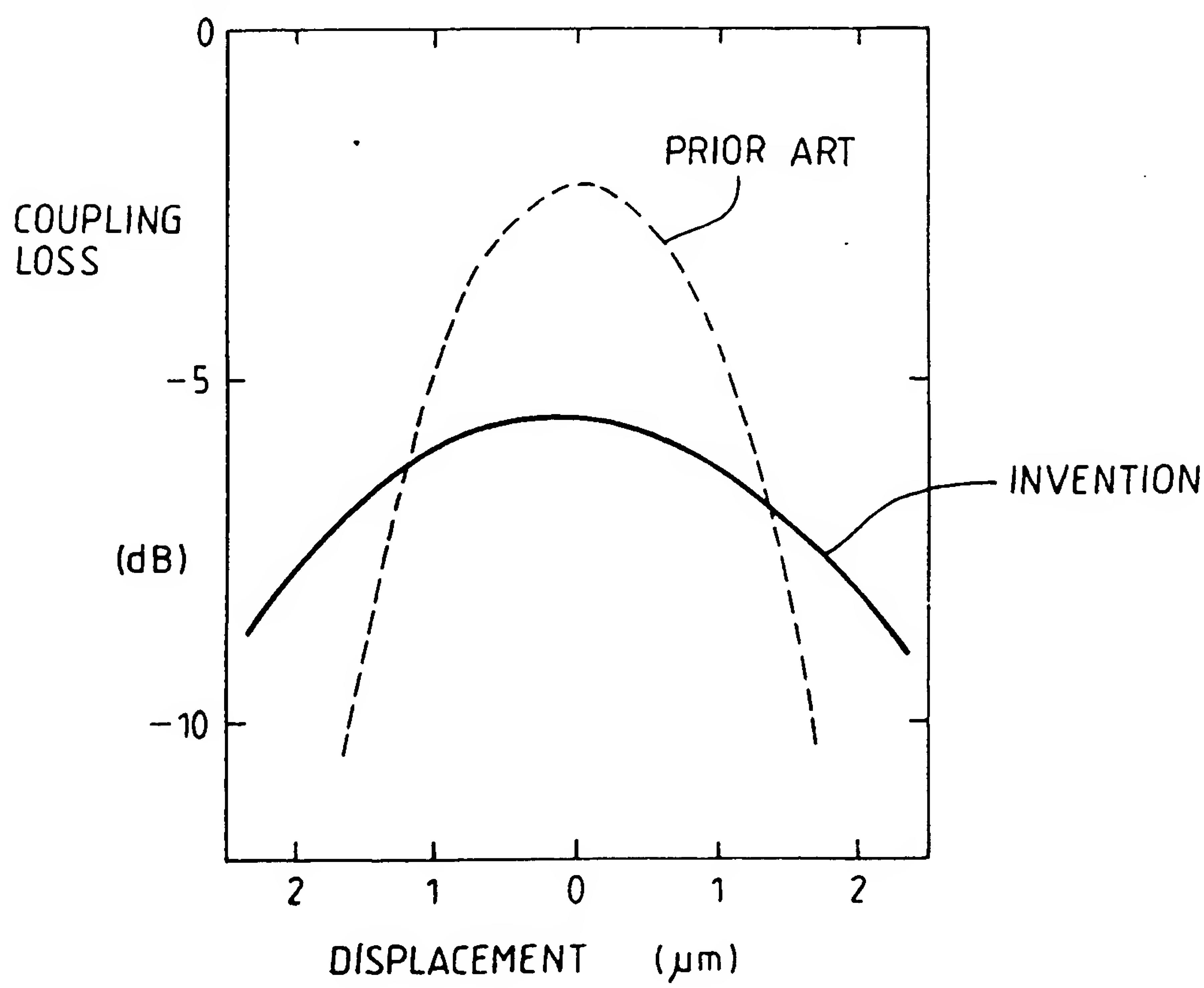

0
-5
-10
COUPLING LOSS
(dB)
PRIOR ART
INVENTION
2
1
0
1
2
DISPLACEMENT (μm)

Fig. 5

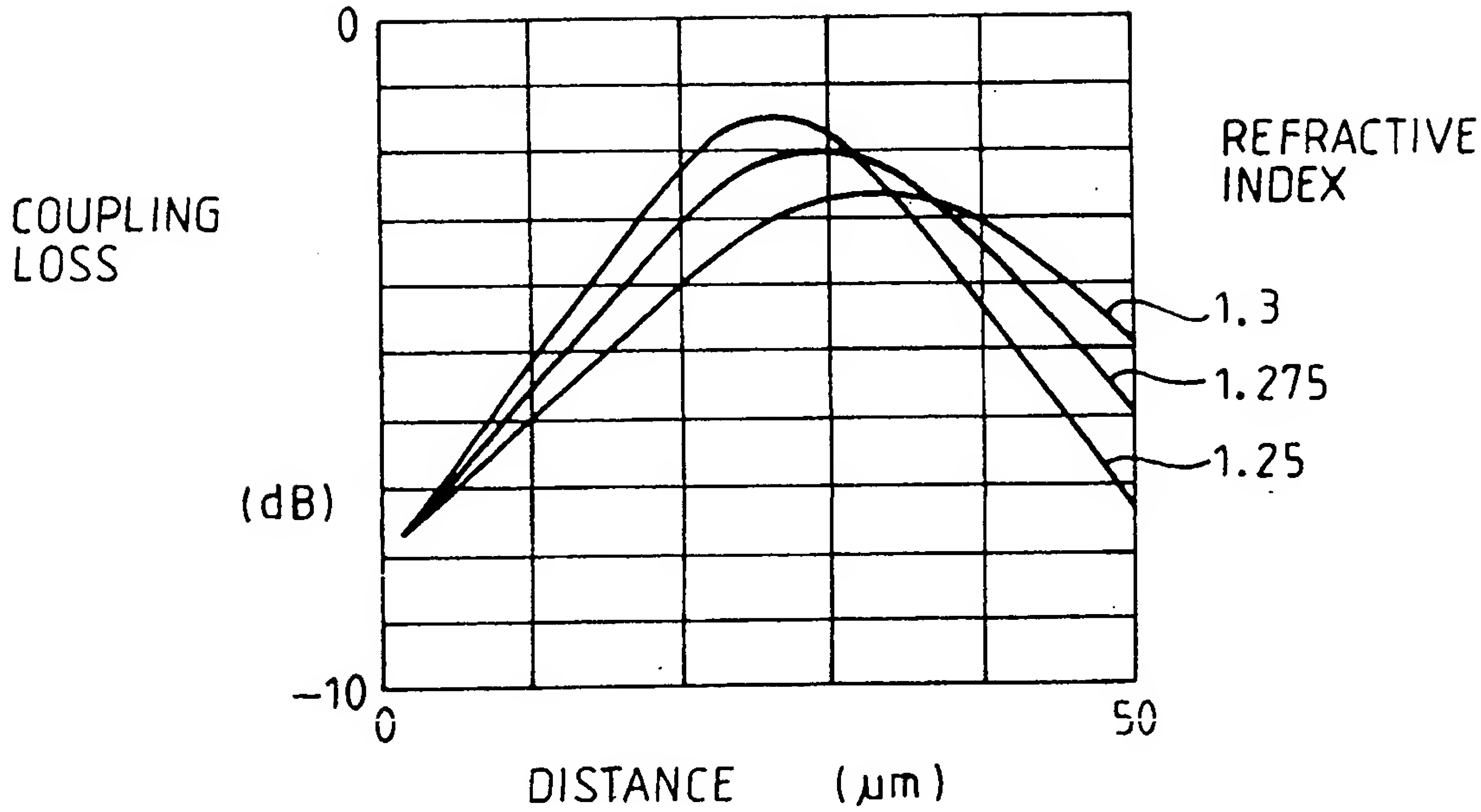

0
COUPLING
LOSS
(dB)
−10
0
50
DISTANCE (μm)
REFRACTIVE
INDEX
1.3
1.275
1.25

Fig. 6

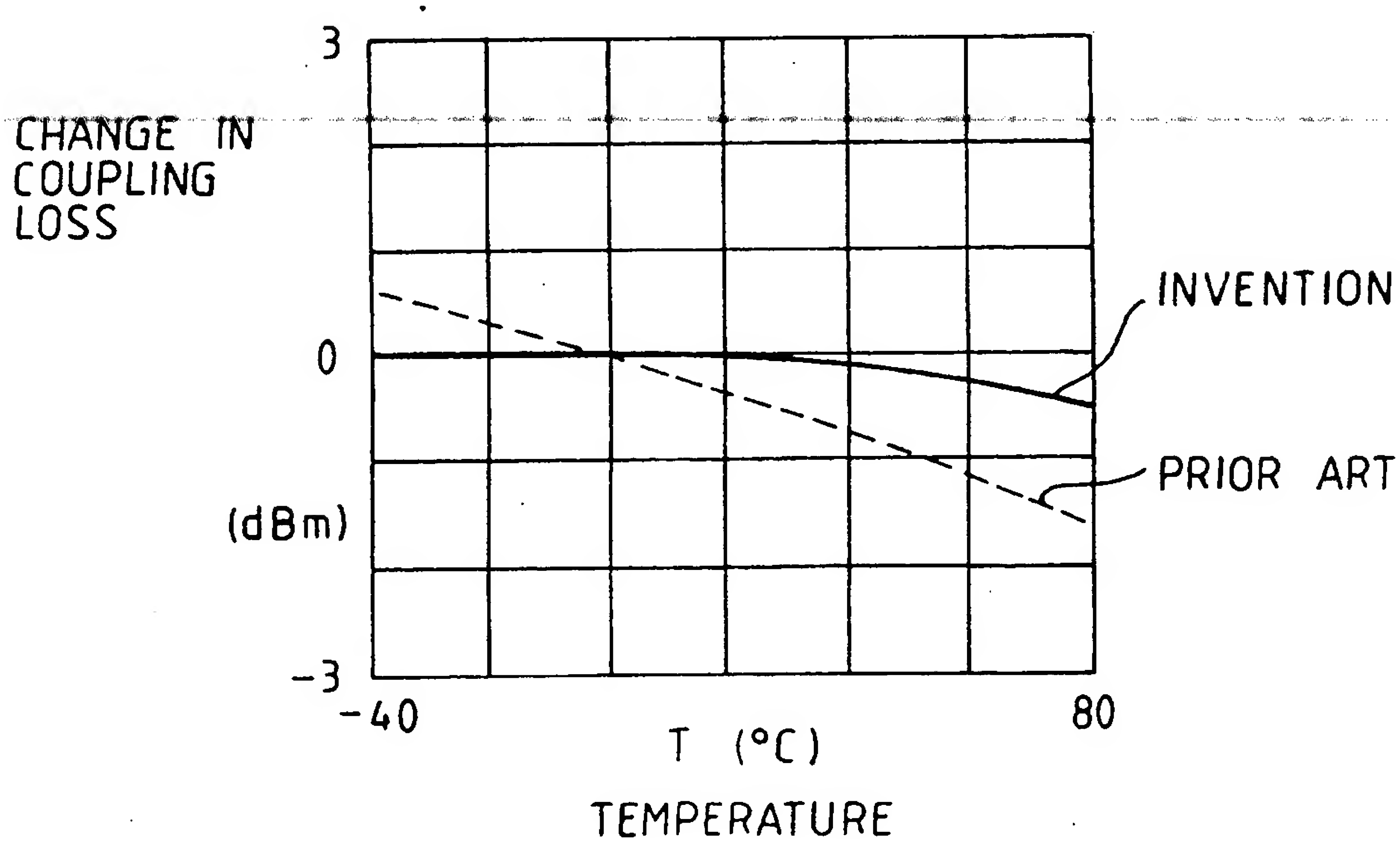

3
CHANGE IN
COUPLING
LOSS
0
(dBm)
−3
−40
80
T (°C)
TEMPERATURE
INVENTION
PRIOR ART

Fig.7 (Prior Art)

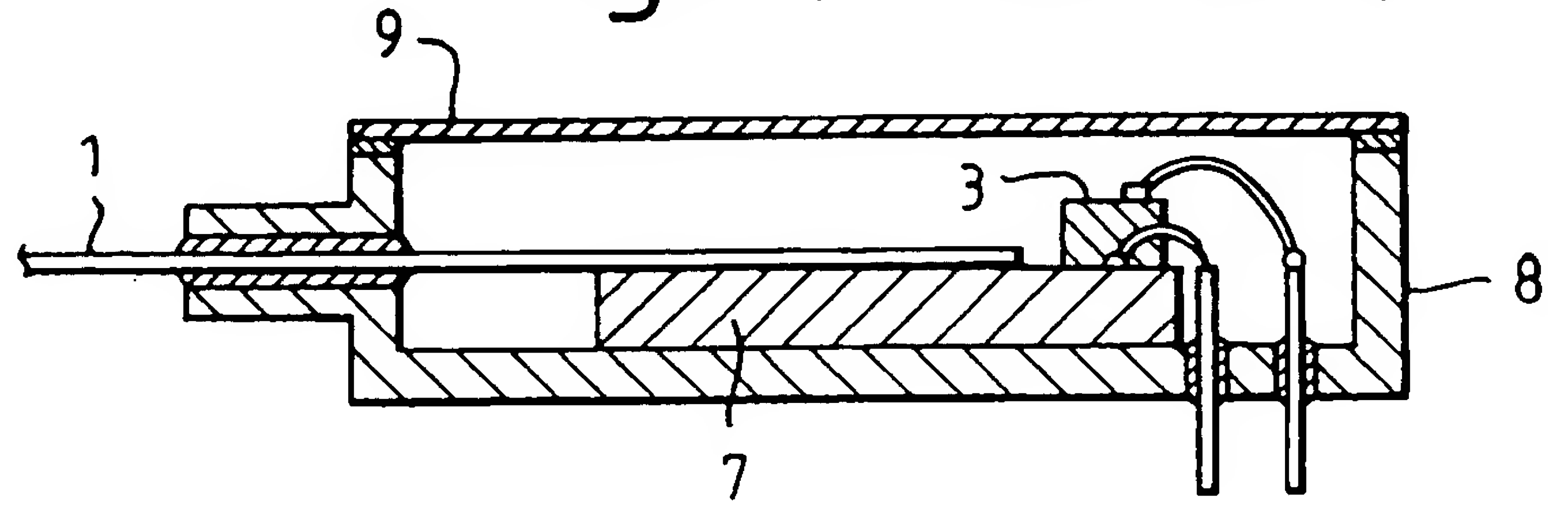


Fig.8

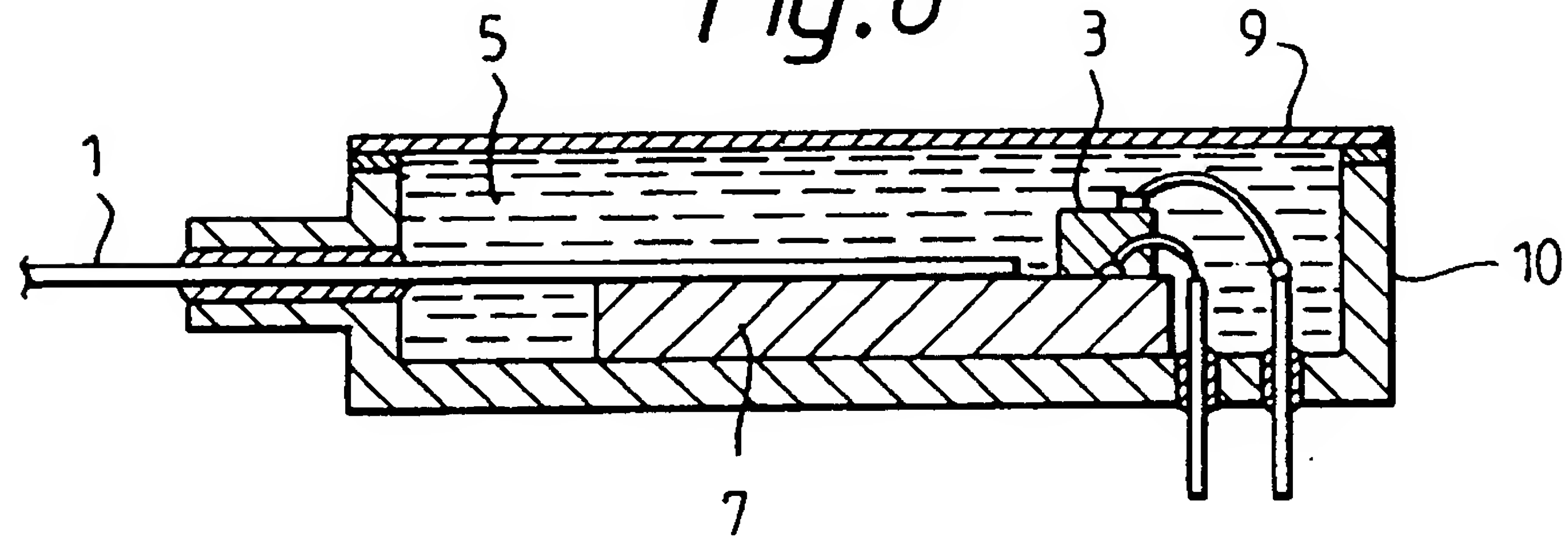


Fig.9

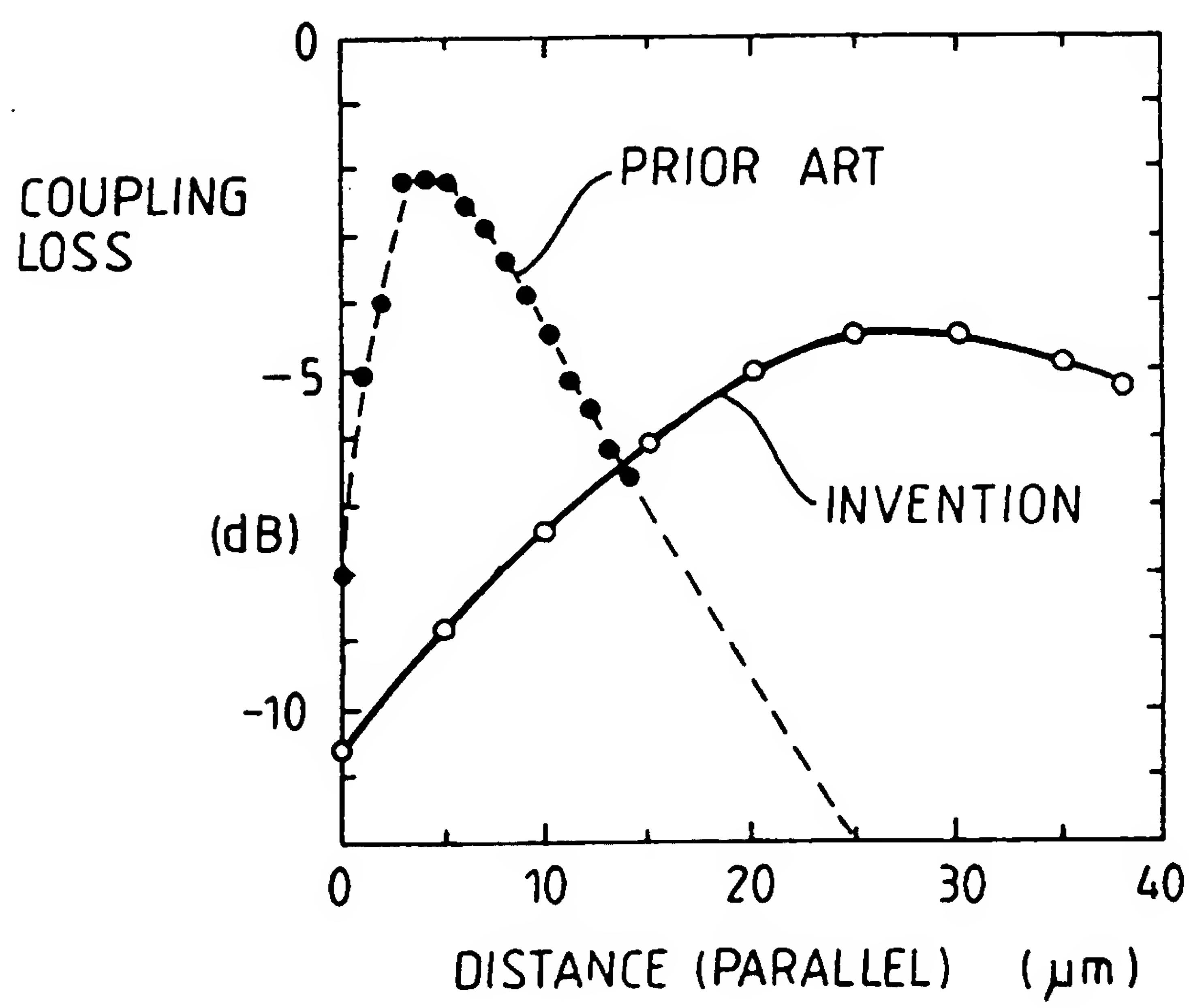


Fig. 10

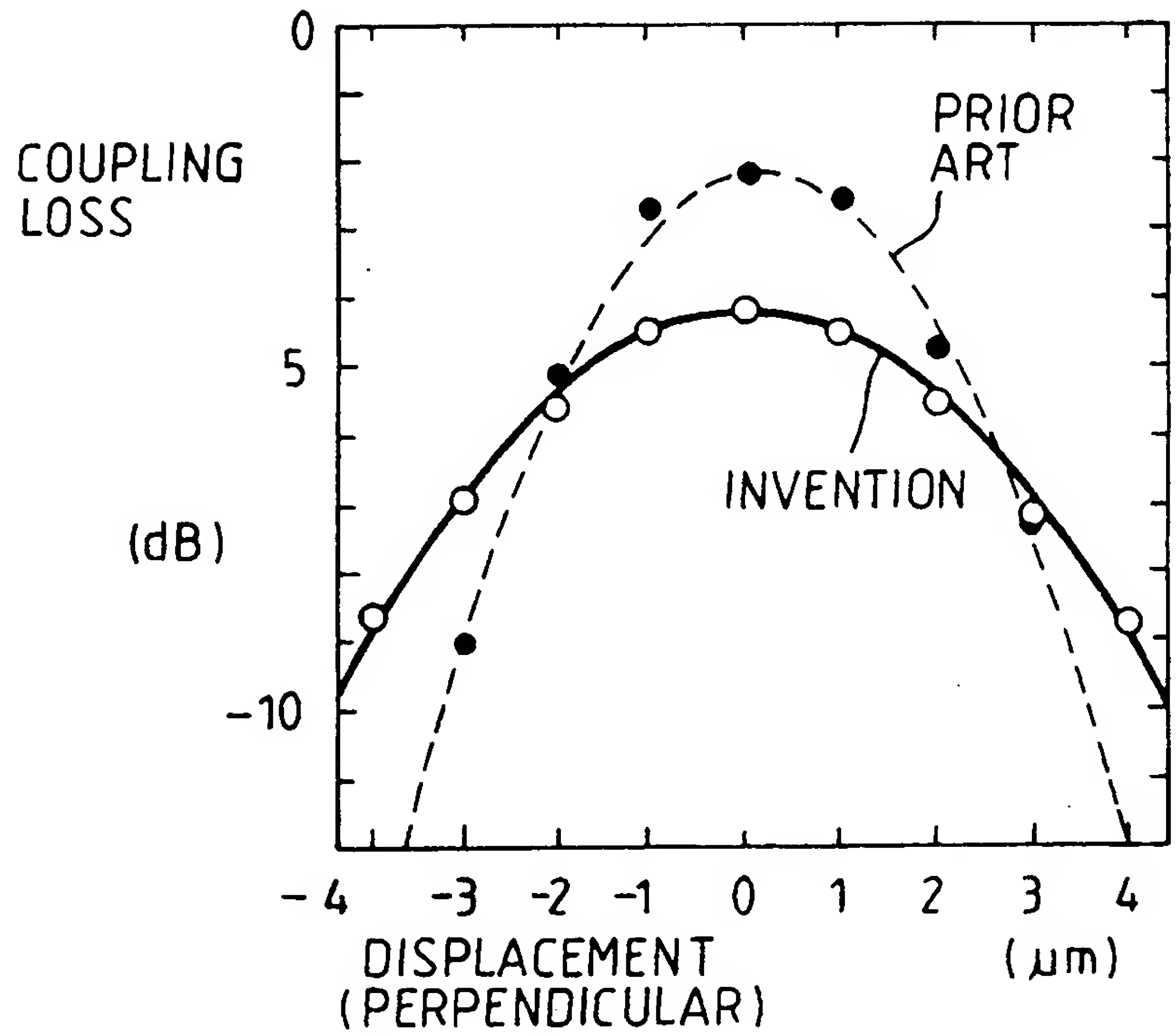

COUPLING LOSS
(dB)
0
5
-10
PRIOR ART
INVENTION
-4
-3
-2
-1
0
1
2
3
4
DISPLACEMENT (PERPENDICULAR)
(μm)

Fig. 11

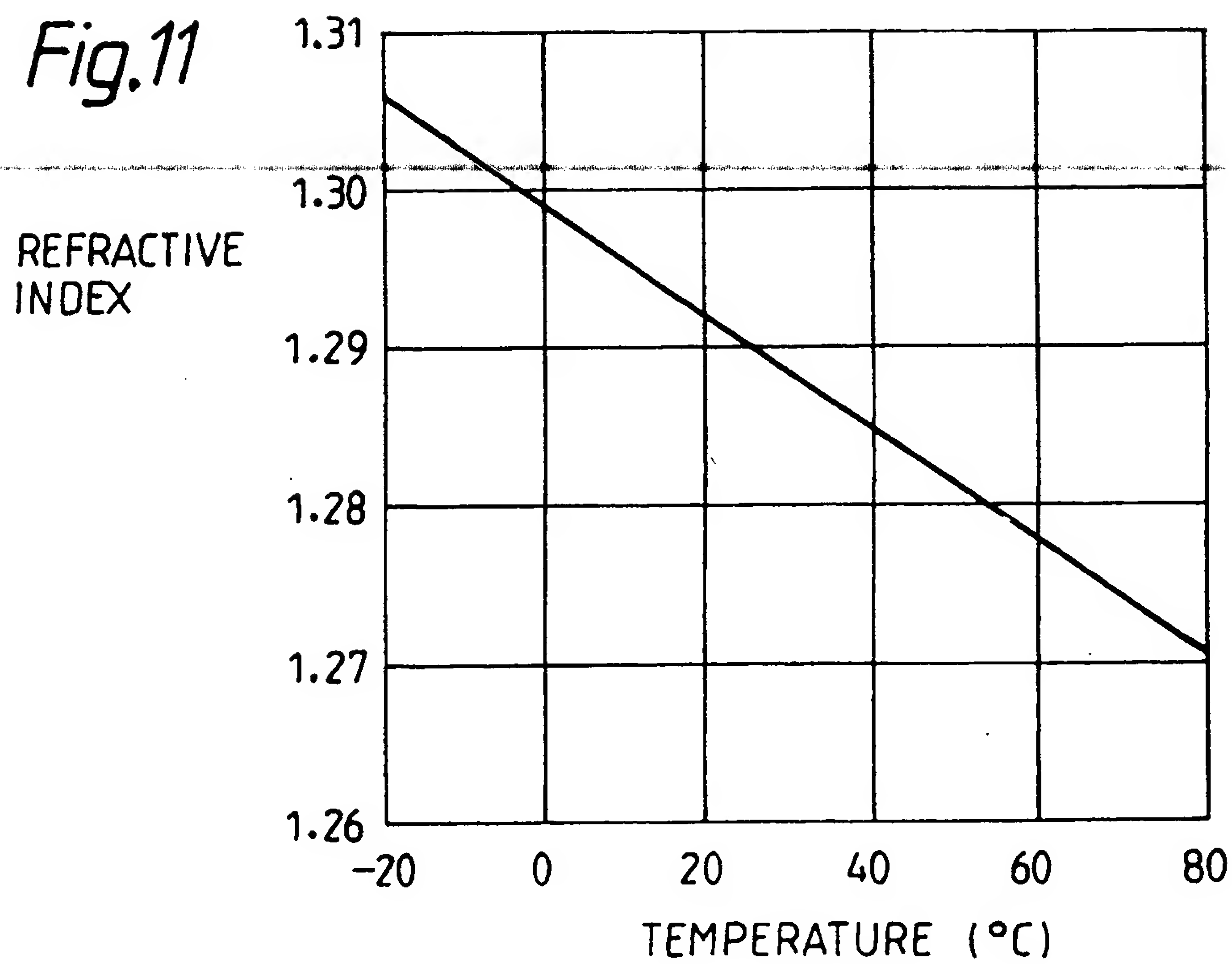

REFRACTIVE INDEX
1.31
1.30
1.29
1.28
1.27
1.26
-20
0
20
40
60
80
TEMPERATURE (°C)

Fig.12 (Prior Art)

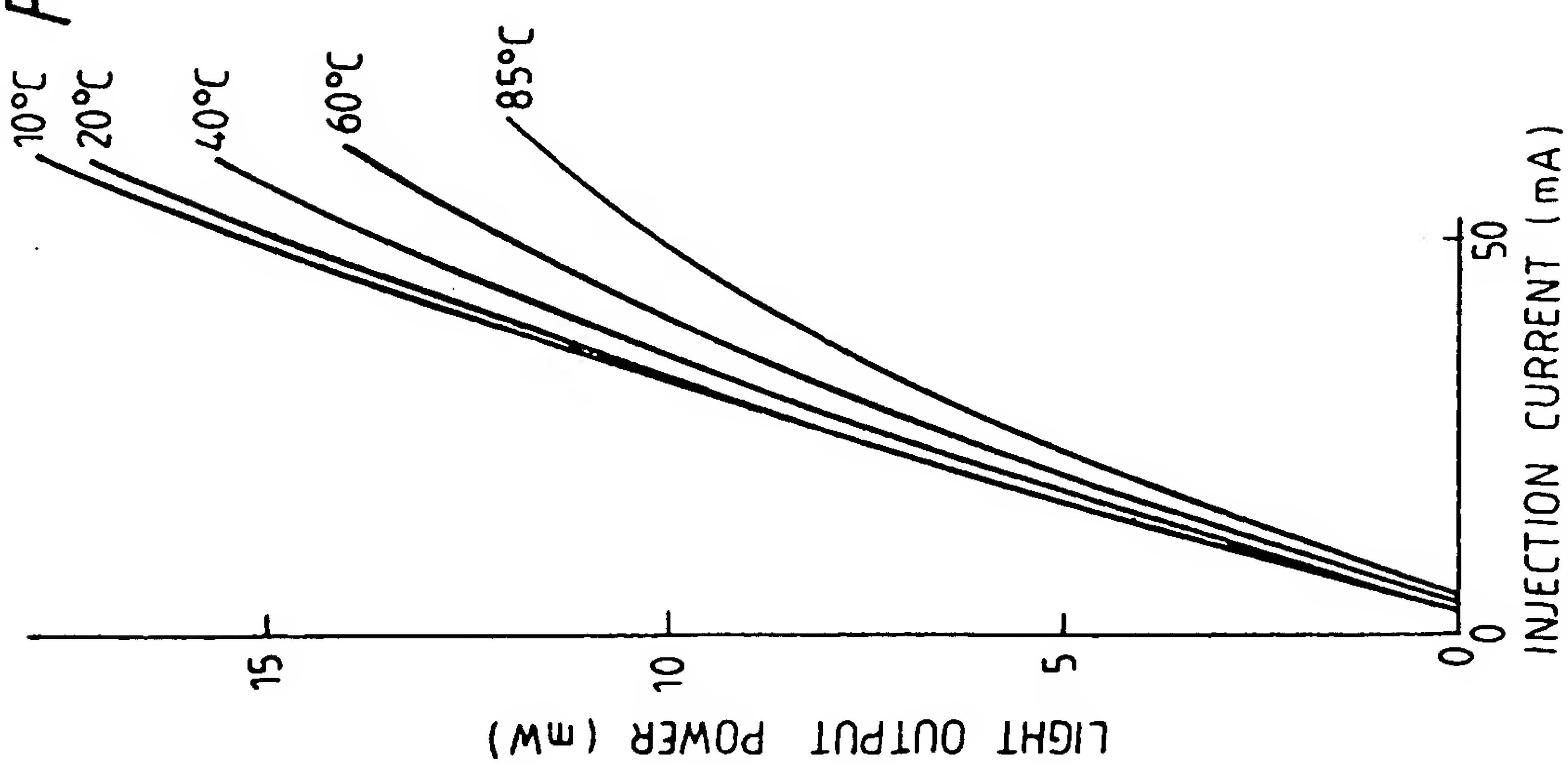


Fig.13

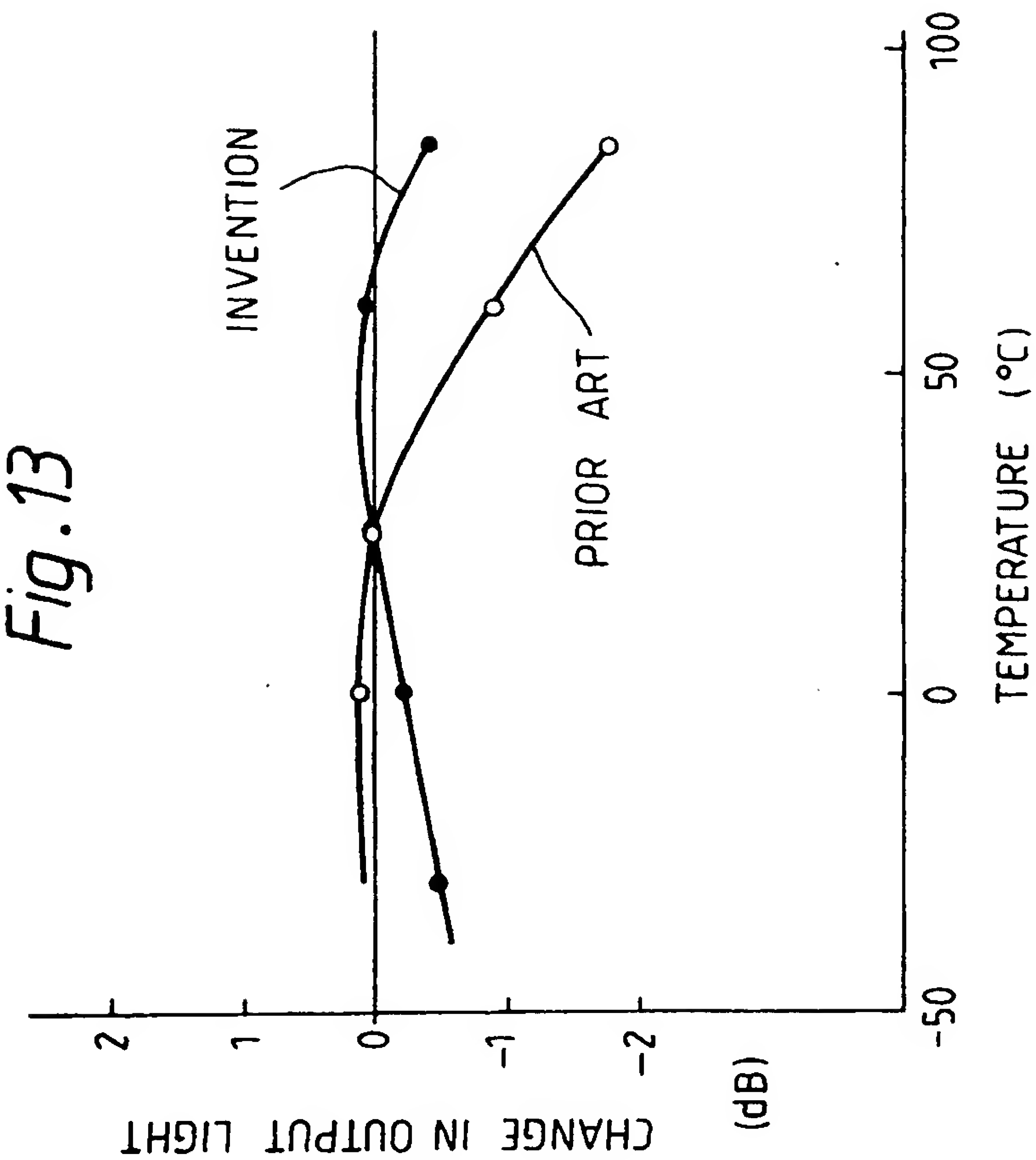
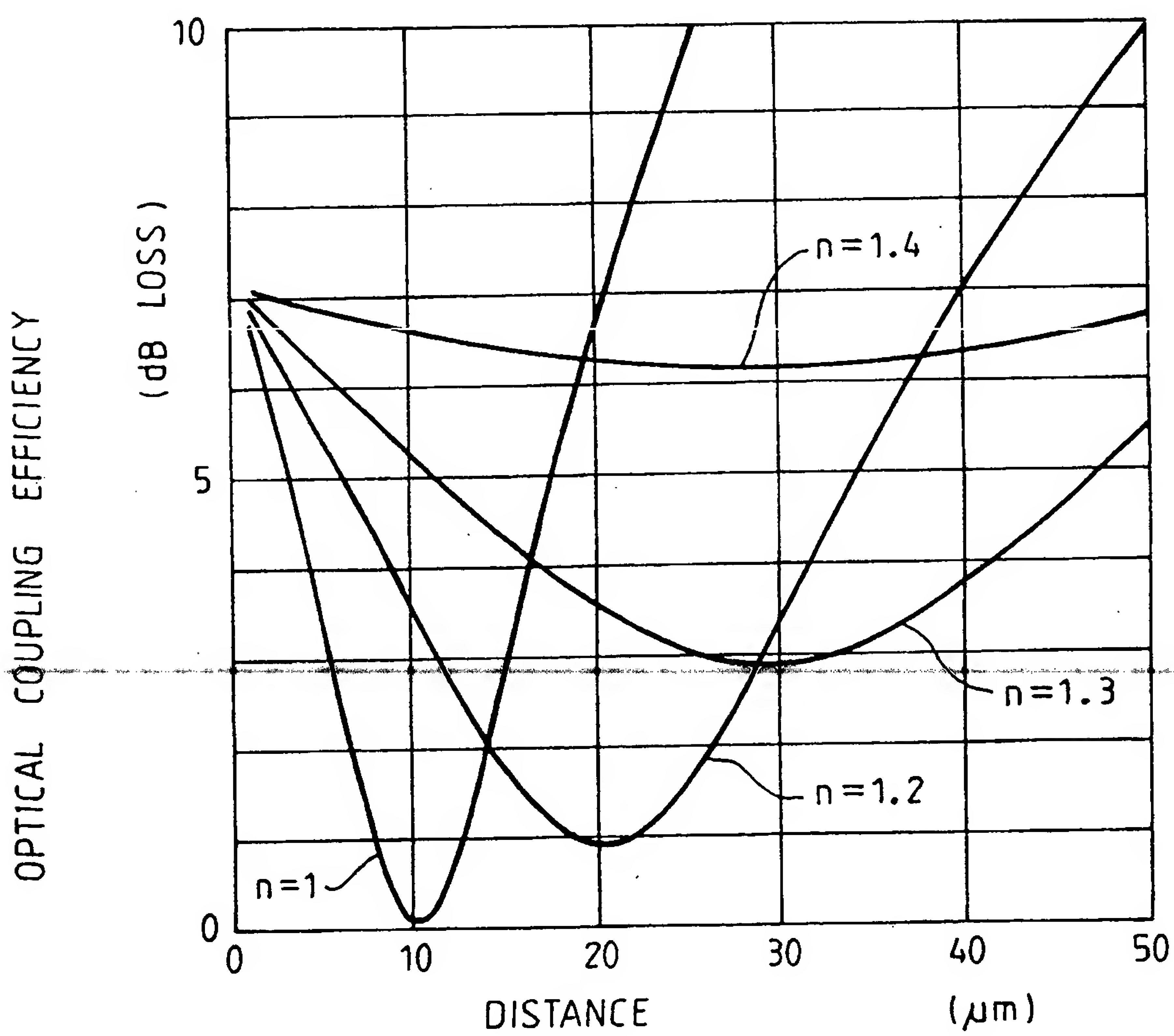


Fig.14

REFRACTIVE INDEX vs OPTICAL COUPLING LOSS (EFFICIENCY)



r = 5 μm

θ=27°